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Multiangle Imaging Spectroradiometer (MISR) global aerosol optical depth validation based on 2 years of coincident Aerosol Robotic Network (AERONET) observations

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[1] Performance of the Multiangle Imaging Spectroradiometer (MISR) early postlaunch aerosol optical thickness (AOT) retrieval algorithm is assessed quantitatively over land and ocean by comparison with a 2-year measurement record of globally distributed AERONET Sun photometers. There are sufficient coincident observations to stratify the data set by season and expected aerosol type. In addition to reporting uncertainty envelopes, we identify trends and outliers, and investigate their likely causes, with the aim of refining algorithm performance. Overall, about 2/3 of the MISR-retrieved AOT values fall within [0.05 or 20% $\times$ AOT] of Aerosol Robotic Network (AERONET). More than a third are within [0.03 or 10% $\times$ AOT]. Correlation coefficients are highest for maritime stations ($\sim$0.9), and lowest for dusty sites (more than $\sim$0.7). Retrieved spectral slopes closely match Sun photometer values for Biomass burning and continental aerosol types. Detailed comparisons suggest that adding to the algorithm climatology more absorbing spherical particles, more realistic dust analogs, and a richer selection of multimodal aerosol mixtures would reduce the remaining discrepancies for MISR retrievals over land; in addition, refining instrument low-light-level calibration could reduce or eliminate a small but systematic offset in maritime AOT values. On the basis of cases for which current particle models are representative, a second-generation MISR aerosol retrieval algorithm incorporating these improvements could provide AOT accuracy unprecedented for a spaceborne technique.

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1. Introduction

[2] Recent discoveries about the impact of airborne particles on regional radiation balance and water cycle [e.g., *Ramanathan et al.*, 2001] are adding significance to the well-established need for an accurate description of aerosols in global climate prediction models and in regional process studies [e.g., *Intergovernmental Panel on Climate Change* (*IPCC*), 2001; *Hansen et al.*, 1997]. Contributions from satellite aerosol products [e.g., *Remer et al.*, 2005; *Torres et al.*, 2002], surface measurements [e.g., *Dubovik et al.*, 2002], and aerosol transport models [e.g., *Tegen et al.*, 1997; *Chin et al.*, 2002] are helping create a global picture of aerosol distributions for these applications. The Multiangle Imaging Spectroradiometer (MISR) instrument is a player in this effort. One of its main goals is to produce frequent, global measurements of aerosol amount and type over a wide variety surface types, including key aerosol source regions, and to provide quantitative accuracy estimates for these values.

[3] MISR was launched into a Sun-synchronous polar orbit, crossing the equator at about 10:30 local time, in December 1999, aboard the NASA Earth Observing System's Terra satellite. It is among a new generation of satellite instruments, unique in having a combination of high spatial resolution, a wide range of along-track view angles, and high-accuracy calibration [*Diner et al.*, 1998]. Global coverage (to ±82° latitude) is obtained about once per week.

[4] MISR measures upwelling short-wave radiance from Earth in four spectral bands centered at 446, 558, 672, and 866 nm, at each of nine view angles spread out in the forward and aft directions along the flight path, at 70.5°, 60.0°, 45.6°, 26.1°, and nadir. Over a period of 7 min, as the spacecraft flies overhead, a 400-km-wide swath of Earth is

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successively viewed by each of MISR's nine cameras. As a result, the instrument samples a very large range of scattering angles, between about 60° and 160° at midlatitudes, providing information about aerosol microphysical properties [*Kahn et al.*, 1998, 2001a]. These views also capture air mass factors ranging from one to three, offering sensitivity to optically thin aerosol layers, and allowing aerosol retrieval algorithms to distinguish top-of-atmosphere reflectance contributions from the surface and atmosphere [*Martonchik et al.*, 1998, 2002].

[5] The MISR standard aerosol retrieval algorithm runs in an operational, fully automatic mode. It reports aerosol optical thickness (AOT) and aerosol type at 17.6 km resolution, by analyzing MISR top-of-atmosphere radiances from 16 × 16 pixel patches of 1.1-km resolution, [*Diner et al.*, 1999a]. On the basis of the prelaunch studies cited above, we expect MISR AOT sensitivity to vary with conditions. We predicted that at least over dark water, for AOT larger than about 0.1 at midvisible wavelengths, MISR aerosol type retrievals should exhibit particle size, shape, and some single-scattering albedo (SSA) sensitivity [*Kahn et al.*, 2001a]. These sensitivities, of interest in themselves, also reduce the MISR AOT retrieval's dependence on assumptions about particle microphysical properties.

[6] This paper aims at assessing how the early postlaunch version of the aerosol retrieval algorithm actually performs. It encompasses MISR level 2 aerosol products having version numbers from F03_0007 through F07_0015, available along with product descriptions and data handling tools from the NASA Langley Atmospheric Sciences Data Center (http://eosweb.larc.nasa.gov). A full chronology of algorithm changes is given on this Web site, by selecting "MISR data," then "data versioning," then "level 2 aerosol."

[7] Our approach is to compare coincident MISR AOT values with those obtained from 32 stations that are part of the Aerosol Robotic Network (AERONET). AERONET is a worldwide federation of ground-based, automated Sun photometers producing spectral AOT, aerosol microphysical properties, and precipitable water using standardized calibration, observation, cloud-clearing, data processing, and data distribution procedures [*Holben et al.*, 1998]. AERONET measurement uncertainties are well-understood [e.g., *Dubovik et al.*, 2000], and the data are widely used as a standard for satellite aerosol retrieval validation. Other MISR-AERONET AOT comparisons focus on southern Africa during August and September 2000 [*Diner et al.*, 2001], on the continental United States [*Liu et al.*, 2004], and on desert regions [*Martonchik et al.*, 2004; *Christopher and Wang*, 2004]. *Abdou et al.* [2005] studied cases where the Moderate resolution Imaging Spectroradiometer (MODIS) instrument, also aboard the Terra satellite, made observations coincident with MISR during 3 months of 2002.

[8] For this study, we selected 32 AERONET stations that capture four broad classes of aerosol air mass types over a 2-year period (Figure 1; Table 1). The data set provides adequate statistics for us to quantify uncertainties based on MISR-AERONET AOT differences, and to evaluate the way these differences depend on season and on expected aerosol type. We explore how patterns in the observed trends and outliers may relate to specific assumptions in the MISR algorithm, such as component particle properties and mixture definitions, surface boundary conditions, and cloud screening, with the goal of further refining the MISR aerosol retrieval algorithm itself.

4. Conclusions

[50] We quantitatively assessed the MISR early post-launch AOT product, over land and ocean, by comparing with a 2-year measurement record of globally distributed AERONET Sun photometers. Our objectives were to provide uncertainty envelopes, and to identify likely causes for any discrepancies that might point toward ways of refining the algorithm.

[51] Several independent analyses demonstrate that MISR aerosol retrieval algorithm performance is already quite good compared with other remote sensing techniques, especially over bright surfaces [*Martonchik et al.*, 2004] and over land in general [*Abdou et al.*, 2005; *Liu et al.*, 2004]. In our study, overall, about 2/3 of the MISR-retrieved AOT values fall within [0.05 or 20% × AOT] of AERONET, and more than a third are within [0.03 or 10% × AOT] in all categories, a more comprehensive result that is consistent with other work. The MISR-retrieved spectral slopes for biomass burning and continental aerosol types are also in close agreement with Sun photometer values.

[52] We grouped together sites where biomass burning, continental, dusty, and maritime aerosols were thought to be dominant, and stratified the data in each group by season. As expected, uncertainties are smallest for maritime stations, and greatest for dusty sites. For example, the standard deviation of AOT differences is only 0.038 for green band maritime events; it is 0.071, 0.076, and 0.104 for biomass burning, continental, and dusty events, respectively (Table 5). Similarly, the correlation coefficient is 0.92 for midvisible maritime, 0.85, 0.87, and 0.73 for biomass burning, continental, and dusty cases. These results reflect in part that it is generally easier to retrieve from space the properties of bright aerosols over a dark water surface than over a bright desert or other land surface. Seventy-nine percent of the maritime central retrievals in this study were derived from the MISR aerosols-over-dark-water algorithm, whereas all the central retrievals in the biomass burning and continental categories, and 98% of the dusty cases, used the MISR aerosols-over-land algorithm.

[53] Detailed analysis of the patterns that emerged in the MISR-AERONET AOT differences suggests that adding to the algorithm climatology spherical biomass burning and pollution aerosol analogs having lower SSA, and replacing existing ellipsoid dust models with more realistic, higher-albedo ones, would reduce the remaining discrepancies for MISR retrievals over land. Fine-tuning the instrument low-light-level calibration and possibly refining the algorithm's ocean surface model could reduce or eliminate a small but persistent offset in maritime AOT values. Also, the addition of a richer set of bimodal and possibly trimodal aerosol mixtures to the algorithm climatology seems likely to allow the aerosol retrieval algorithm to take advantage of additional information in the MISR data. In a few cases over land, where aerosol plumes are likely to occur, we were able to trace outliers to actual scene variability on 10-km scales; we expect that high-wind conditions over ocean may account for some outliers in the maritime data set.

[54] Assessing the quality of MISR-retrieved aerosol type, and re-evaluating AOT sensitivity for an upgraded algorithm, are the subjects of continuing work. On the basis of cases for which current particle models are representative, the second-generation MISR aerosol retrieval algorithm incorporating improvements identified here could reduce the discrepancies overall by at least half, providing AOT accuracy unprecedented for a spaceborne technique.